Geology of the Solomon and New Hebrides Islands, as Part of the Melanesian Re-entrant, Southwest Pacific[1]

P. J. COLEMAN[2]

THE SOLOMON ISLANDS and the New Hebrides Archipelago are examples of fractured island "arcs," autochthonous geological systems, in which patterns of straight-line fractures and vertical and horizontal movement of blocks are the dominant structural feature. The two groups have similar but yet distinctive geologies. They have been studied systematically only over the last 20 years, so that many of their features are still not understood, but it is clear that the results so far obtained amount to a significant contribution to the understanding of fractured island arcs and, by extrapolation, to the understanding of the genesis and development of the southwestern Pacific.

The aim of this paper is to present a synoptic account of the essential geology of the Solomon and New Hebrides groups. That is, it is the rock types and successions, their ages and structure, which are stressed. But certain geophysical evidence is also incorporated, particularly where the geological implications are clear, even though some of this evidence is discussed in detail in the accompanying paper in this issue (Furumoto et al., 1970). There is some repetition, but this is preferable to fostering a sense of dichotomy between the geology, *sensu stricto,* and the geophysics—especially in this area where there is usually a nice correspondence between geological and geophysical data.

Apart from the writer's own field and laboratory studies, the account which follows derives from a variety of major sources. For the Solomons they include published and unpublished results from Geological Survey personnel, past and present, in particular: J. D. Bell, J. C. Grover (former Director), B. D. Hackman, P. Pudsey-Dawson, and R. B. Thompson (Director); also studies by R. L. Stanton (University of New England), a long-term worker in the area; F. K. Rickwood (British Petroleum Company); A. A. Day (University of Sydney); J. G. Speight and D. H. Blake (Commonwealth Scientific and Industrial Research Organisation, Canberra); and Y. Miezitis (Bureau of Mineral Resources, Canberra). Certain geological and geophysical information obtained by the recent United Nations Special Project (Director: H. Winkler) and by expeditions from the University of Wisconsin and the Hawaii Institute of Geophysics (Director: G. P. Woollard) has been incorporated.

For the New Hebrides the main sources include, similarly, the work of the Geological Survey (D. I. J. Mallick, Senior Geologist; A. H. G. Mitchell and A. J. Warden, former Senior Geologist); G. P. Robinson (British Petroleum Company); K. Liggett (New Zealand Geological Survey); also published work by Mawson (1905), Obelliane (1958), de la Rüe (1937), and Sagatzky (1959).

I am particularly indebted to the people of the Geological Surveys, not simply for their information and encouragement, but also for help in the field, often given at the cost of inconvenience and personal discomfort.

REGIONAL FRAMEWORK

The Solomon Islands and the New Hebrides Archipelago are prominent elements within the Melanesian Re-entrant. This is one of the more forceful aspects of Carey's Tethyan Torsion System (Carey, 1963). On any recent bathymetric map of the southwest Pacific it shows as a great angle jutting into the Pacific Basin. The apex is the area of the Fiji-Tonga groups; the northern boundary is at first neatly defined by New Ireland and the Solomons, and then by a markedly en echelon arrangement of bathymetric highs and lows which form the northern edge (Fairbridge, 1961) of the Fiji Plateau (badly named on many maps as the North Fiji or Pandora Basin); the eastern limb is sharply defined by the line of the Tonga and Kermadec

[1] Manuscript received December 2, 1969.

[2] Geology Department, University of Western Australia, Perth.

islands, which connect with the north island of New Zealand. The New Hebrides form, as it were, a minor re-entrant which at their southern end swings to the northeast by way of the Hunter Ridge, connecting with Fiji and so containing the Fiji Plateau (Fig. 1).

The Melanesian Re-entrant and much of the area within it is made of elongated crustal blocks which find topographic expression as island chains. New Caledonia, with the Loyalty Islands, is an advanced example, so that a large part of the block is now a land mass; the Tonga-Kermadec Block is youthful, the islands being relatively small and widely separated; the Solomons and New Hebrides come between and are good examples of so-called fractured island arcs.

Within the Re-entrant there are rhombochasms (the Coral Sea is a large one, New Georgia Sound in the Solomons is small but well defined), sphenochasms (the Tasman Sphenochasm, between southeast Australia and the Lord Howe Rise, is the most obvious), and orotaths (the Kermadec-Tonga Ridge is named as such by Carey). These are Carey's terms for features which accompany crustal sundering and spreading (Carey, 1958).

Emphatic straight-line lineaments are common; curved or arcuate lineaments are less so, and some of those shown even on modern maps may represent the subjective, rounding-off touch of the cartographer. Others are probably real—for example, those of the Hebrides-Hunter Trench and the markedly rotational, curved features of the eastern Fiji Plateau. Horsts and graben dominate the structure, even of particular islands, so that in general the region exemplifies the taphrogenic structural style. Tensional effects are—and appear to have been—the rule. The rim of the Re-entrant and the New Hebrides is tectonically unstable and seismically active; the New Hebrides are an area of intense seismicity. The Solomons, New Hebrides, and other parts of the Re-entrant are areas of markedly anomalous positive gravity (Furumoto et al., 1970; Malahoff and Woollard, 1969).

The Solomon Islands, which help define the northern limb of the Re-entrant, are in part a double chain closed at the northwestern end by Bougainville and at the southeastern end by San Cristobal. The northern flank of the group is made up of large islands with a distinct en echelon disposition (Bougainville–Choiseul–Isabel–Malaita). A minor deep reflects this arrangement and separates the Solomon Block from the Ontong Java Platform, which supports Ontong Java and other prominent atolls. This platform is a tectonically puzzling feature; it may be a remnant of the Darwin Rise (Menard, 1964). New Georgia Sound, a severely rhombic depression 2,000 meters deep, separates the north and south flanks. The latter (Bougainville–New Georgia–Russell–Guadalcanal–San Cristobal) shows some offsetting of the islands but is not so regularly en echelon as the north flank. Over its middle portion, it appears to be linked by NE-trending horst and graben with the Louisiade-Rennell Ridge (Krause, 1966). The east part of the flank, however, is delineated by the South Solomon Trench (about 7,000 meters), as is Bougainville, at the other end, by a part of the Planet Deep (9,000 meters) (Fig. 1).

The axis of the Solomon Block appears sigmoidal, but this is probably accidental and reflects the relative dominance of one or the other of two lineament sets with preferred orientations, NW–SE and W–E, respectively. These sets, with a third subsidiary one trending NE, define the outlines and relative positions of the larger islands. To the west, the Block ends with the Lihir group of small volcanic islands, which are separated by a minor deep from New Ireland. This connects with northern coastal New Guinea by way of the "swirl" of the Bismarck Archipelago (New Britain, New Ireland). At its eastern end, the Block is terminated transversely by the northern extremity of the New Hebrides Block. This "cut-off" relationship is shared by the South Solomon Trough, terminating against the Torres Trench, and is reflected on the northeastern flank by the confused bathymetry in the area east of Ulawa, with its pocket depressions (Ulawa Deep) and linear deeps (Cape Johnson Trough).

The New Hebrides lie within the Re-entrant. Although not so markedly as the Solomons, the New Hebrides Archipelago is also in part a double chain, closed at the north by the Santa Cruz group and at the south by a tail of volcanic islands (Epi–Efate–Erromango–Tanna–Aneityum) (Fig. 2). The axis of the New Hebrides Block is slightly sigmoidal, marked by a line of active and recent volcanoes. As with

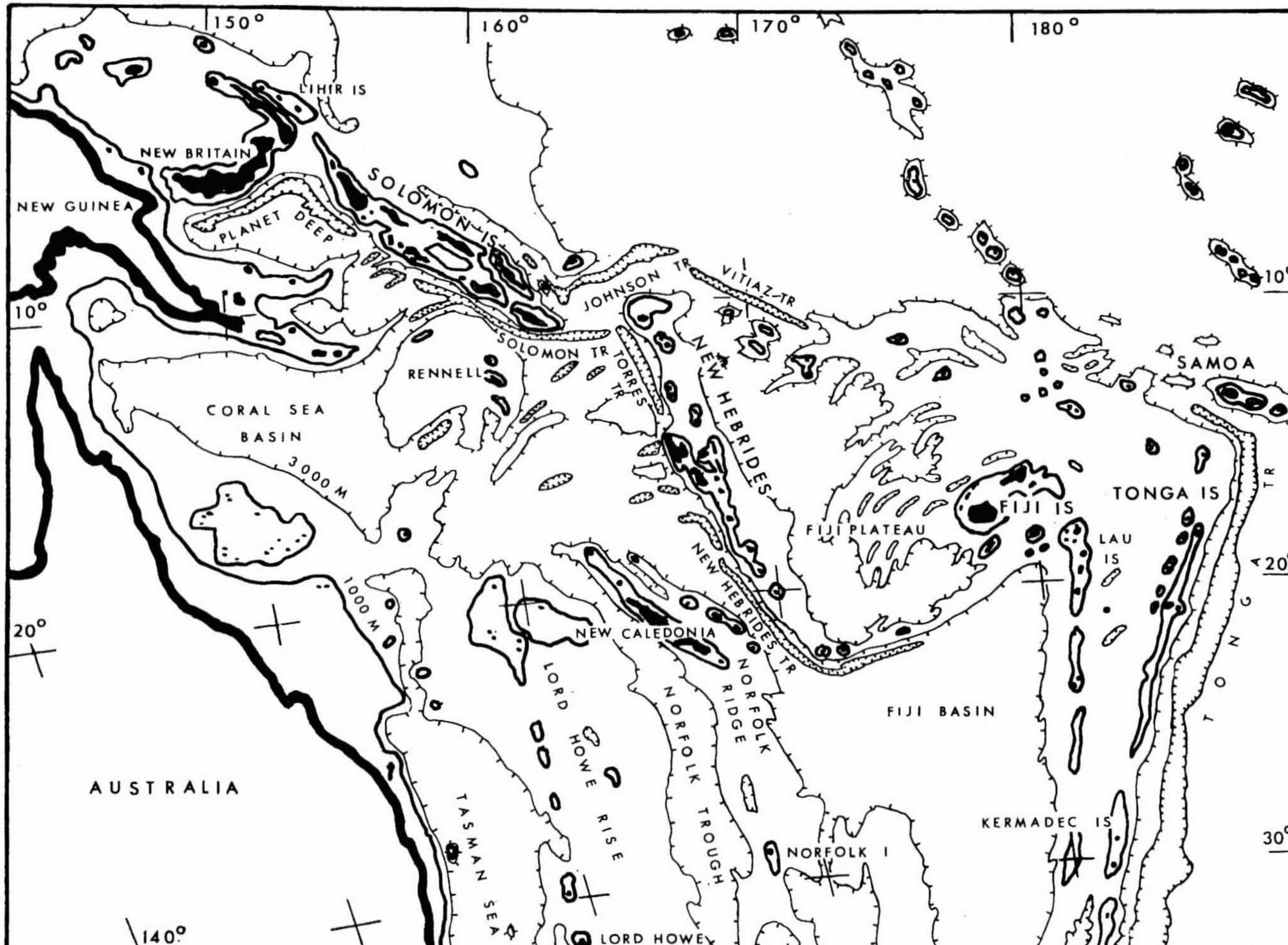

FIG. 1. Generalized bathymetric and locality map of the Melanesian Re-entrant. Bathymetry based on data from North American Aviation/Autonetics; *The Times* Atlas of the World; and H. W. Menard and colleagues. Contours: *heavy line,* 1,000 meters; *open hachured line,* 3,000 meters. Trenches and linear deeps: *enclosed, close hachured line.*

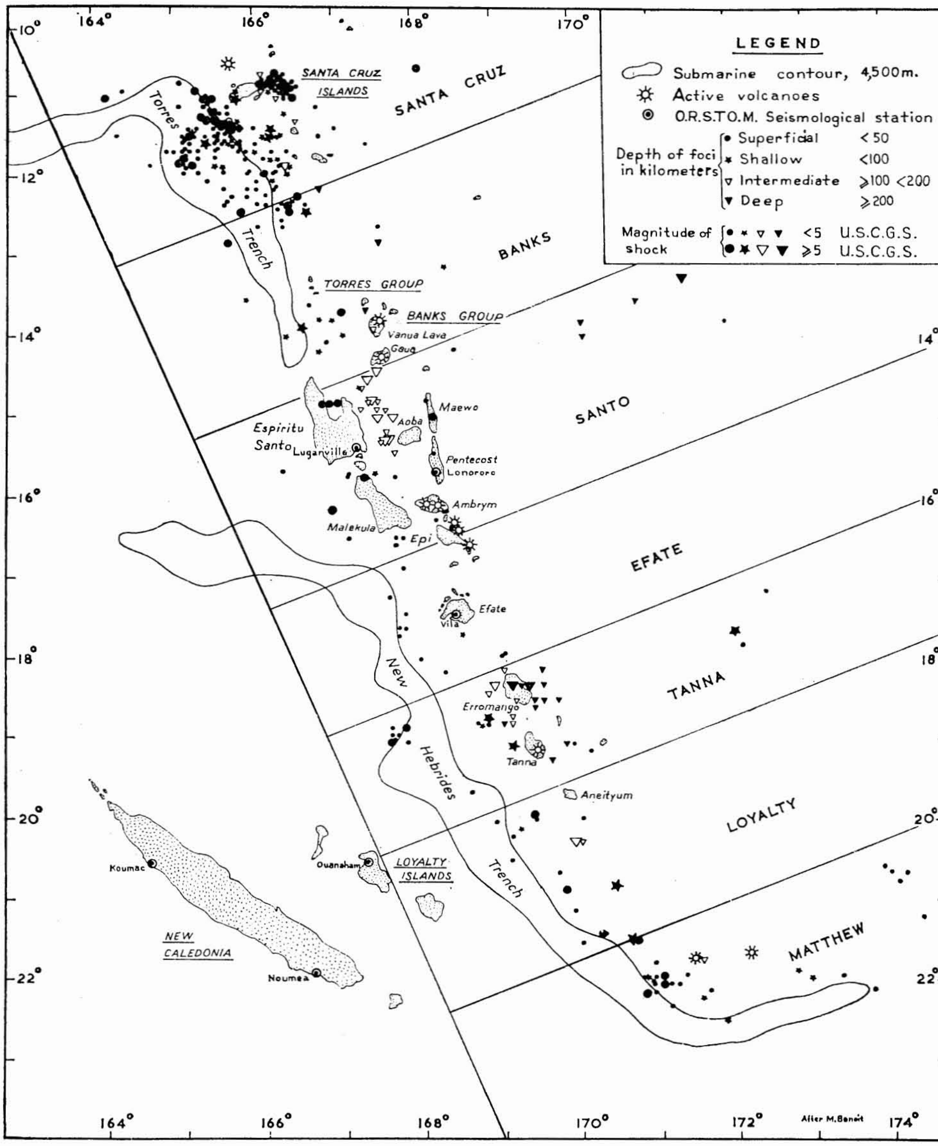

FIG. 2. Locality map of the New Hebrides Archipelago with seismicity for 1967 (after Benoit in Mallick, 1969).

the Solomons, it has deeps on the "reverse," that is, continental, side (Torres Trench to the north and New Hebrides Trench to the south), which are separated by a shallower middle portion. This has E–W trending horsts and graben which tail off into the New Hebrides Basin and in part connect with the southerly extension of the Rennell Ridge. The eastern flank passes more or less smoothly into the deeper water covering the Fiji Plateau. To the north, the New Hebrides Block ends with a deep—part of the Johnson Trough–Vitiaz Trench complex. At the south, the trench swings to the east, becoming the Hunter Deep and is not crossed by any connection with the nearby New Caledonia-Norfolk Ridge. As a block, the New Hebrides is relatively isolated.

The high seismicity of the Solomon and New

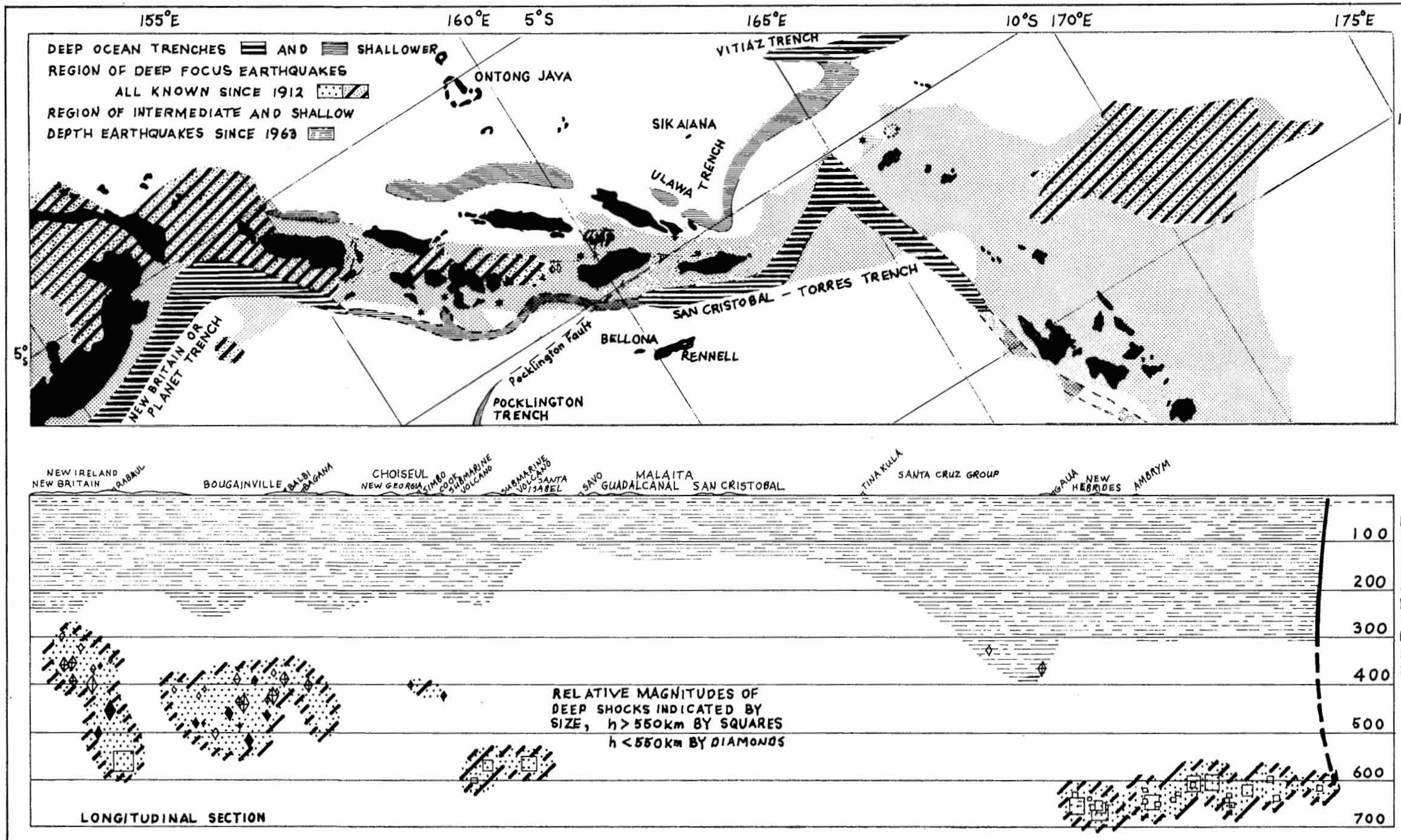

FIG. 3. Seismicity in the Solomon Islands (after Grover, 1969).

Hebrides blocks is a noteworthy regional feature (Grover, 1969) (Fig. 3).[3] Over the Solomon Block most of the earthquake shocks are of shallow focus, less than 60 km, and tend to be distributed along the southern flank of the Block, adjacent to the northeastern side of the Solomon Trough and the east Planet Deep. Intermediate shocks (70 to 300 km) are concentrated at each end, in the Planet Deep and Guadalcanal–San Cristobal areas; a few intermediate and deep shocks have been recorded below New Georgia Sound, northeast of New Georgia Island. In profile, the seismic zone is either near-vertical or steeply inclined toward the Pacific—an unusual case. The longitudinal profile is asymmetric, the deepest hypocenters, up to 500 km, being confined to the western end. Allowing for a wide margin of error in fixing the hypocenters, certainly exceeding 25 km for the deeper shocks, it does seem that there is something of a gap in their distribution between 200 and 400 km, and that centers deeper than 500 km are extremely rare. Miyamura (1968) considers that a gap in the distribution of intermediate-depth hypocenters is a feature of the seismicity of the circum-Pacific regions.

The significance of the seismic pattern with regard to local regional structure is not readily apparent. At least superficially, the areas of deep foci relate to the deeps at each end of the southern flank of the Solomon Block, but what this means is uncertain. Similarly, there is a very approximate link of intermediate centers with some of the areas of highest positive gravity anomaly, but again it is not clear why this should be so (Fig. 4).

The New Hebrides Block is an area of even higher seismicity and is, indeed, one of the most active in the world. Most shallow shocks originate below a belt along the western edge of the Block. Distribution is fairly even, although there is some concentration of foci at the Santa Cruz end, where the South Solomon Trough abuts against the Torres Trench (see Fig. 3). Intermediate and deep hypocenters are more common and more evenly distributed than in the Solomon Islands region. They indicate a steep easterly dip for the seismic zone, although not as steep as the Solomons example. If the Fiji Plateau is regarded as "continent," then the seismic zone, the trenches, and the distribution of volcanic centers become more nearly "normal."

As with the Solomons, but less spectacular in detail, the New Hebrides area also shows abnormally high positive gravity anomalies. These do not seem to be related directly to the seismic pattern.

Earlier published estimates of crustal thickness in the Solomons and New Hebrides areas were based on slender seismic evidence and preliminary gravimetric results (Officer, 1955; Coleman and Day, 1965). The value given was 15 km or less. Later seismic and gravity evidence suggests that this is a minimum value and that the actual thickness varies between 20 and 30 km over the combined length (over 2,000 km) of the two groups. A tentative estimate (unpublished) by the Bureau of Mineral Resources, Canberra, for the arc of the Bismarck Archipelago is more than 30 km. The structural and gravity picture is consistent with considerable but varying uplift of crustal and subcrustal blocks, so that variation in estimates of crustal thickness could be expected.

GEOLOGY OF THE SOLOMON ISLANDS

The major geological features of the Solomon Islands have been described by Coleman, Grover, Stanton, and Thompson (1965), and Coleman (1965, 1966*a*). These papers include reference to others which provide details, especially of the geology of individual islands. The reader is also referred to the revised regional geological map of the British Solomons (British Solomon Islands Geological Survey, 1969). The summary given here includes observations obtained over the last few years.

The Solomon Islands are an autochthonous geological system; that is, the rocks present in the area originated within it and are not derived from some nearby separate entity. On the basis of rock type and structure the group can be divided into three provinces: the Volcanic, Central, and Pacific provinces (Coleman, 1965) (Figs. 5 and 6).

The Volcanic Province includes nearly all of

[3] The most recent seismic picture for the New Guinea–Solomons region is given by Denham (Journal of Geophysical Research, vol. 74, no. 17, pp. 4290–4299).

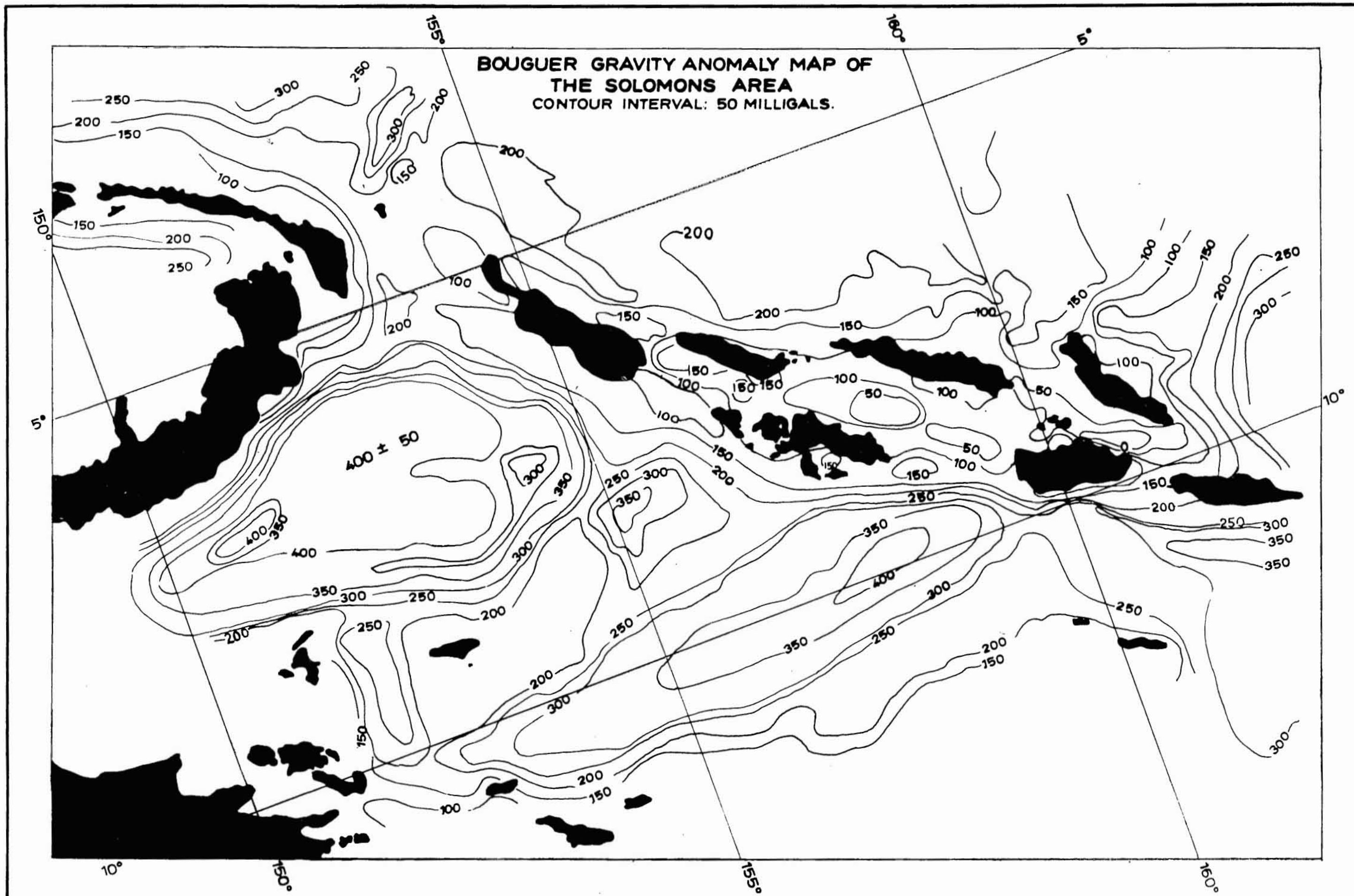

FIG. 4. Regional Bouguer gravity anomalies in the Solomon Sea area (after Rose et al., 1968).

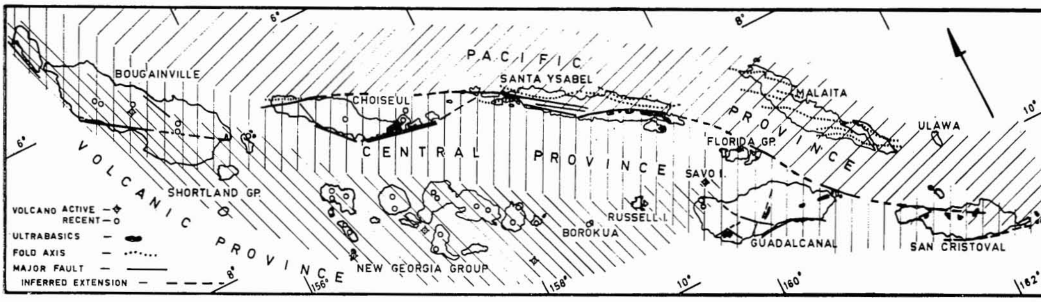

FIG. 5. Geological provinces in the Solomon Islands, with major faults and distribution of volcanoes and ultrabasic bodies.

the active and recent volcanoes. It is boomerang-shaped, the western arm trending NW–SE, the eastern and shorter arm, roughly W–E. The apex is centered on the New Georgia group, which is an assemblage of cones linked by their own extrusives and by fringing and barrier reefs. According to Stanton and Bell (1969), the lavas in this most typical part of the Province range from highly mafic picrite basalts, containing over 50 percent olivine, to hornblende andesites. Olivine basalts and pyroclastics are most common, along with basaltic andesites. Stanton and Bell consider that petrogenetically, "the suite appears to have affinities with both mid-ocean and island-arc associations, the latter to much lesser degree."

Eastern New Georgia Island has a noteworthy occurrence of a coarse-grained pyroxene diorite, a stock intrusive into the lavas and possibly of Quaternary age (Wright, 1969). There are relatively few active volcanic centers but a great many (over 35) well-preserved cones. Most of the current activity is on Bougainville, where there is an overlap of the Volcanic and Central provinces. The lavas and pyroclastics in this part of the Province, as described by Blake and Miezitis (1967), are dominantly hornblende andesites, although augite andesites are not uncommon. Basalts are rare. These authors regard the volcanic suite as being fairly typical of the orogenic calc-alkaline suite. The presence of older diorite, granodiorite, and similar granitoid rocks in this intruded part of the Central Province may have affected the petrography of the younger intrusives.

The eastern arm includes two active submarine volcanoes, Mborokua Island, the Russell group (the northern remnant of a collapsed volcano) and, with Savo, the western tip of Guadalcanal.

Three sets of faults are found in the Volcanic Province. In the west, a NW–SE set is dominant, reflected by the elongation of Bougainville and the disposition of its volcanoes, more or less along the axis of that island. The eastern arm of the Province reflects the dominance of a W–E trending set, parallel to the southeastern side of New Georgia Sound. These sets meet and are equally important in the New Georgia group; this was probably a controlling factor in the origin and development of New Georgia. As well, a third set is conspicuous here. This set trends NE, is probably tensional, and is marked by the linear disposition of cones. The fault pattern shown in the Province is a common one throughout the Solomons (Fig. 7).

The Volcanic Province, in terms of the continuing development of the Solomons, may be regarded as a youthful extension, a young version, of the Central Province. The Central Province has a Mesozoic basal complex (Lower Cretaceous being the older age limit) made up of chloritic "greenstones" and amphibolitic schists, and less altered basic lavas. It also includes lightly metamorphosed, so-called pelagic sediments or deep-water oozes and, possibly, small bodies of gabbroic and granitoid rocks (the age of some of these is uncertain). On Choiseul, at least, the albite-epidote-amphibolite rocks were metamorphosed in the Lower Eocene (Richards et al., 1966).

This basal complex is intruded and covered by Upper Eocene–Oligocene intrusives, lavas, and volcanic agglomeratic and pyroclastic layers; basalts and basaltic pillow lavas predominate, although andesites are also common. The lavas

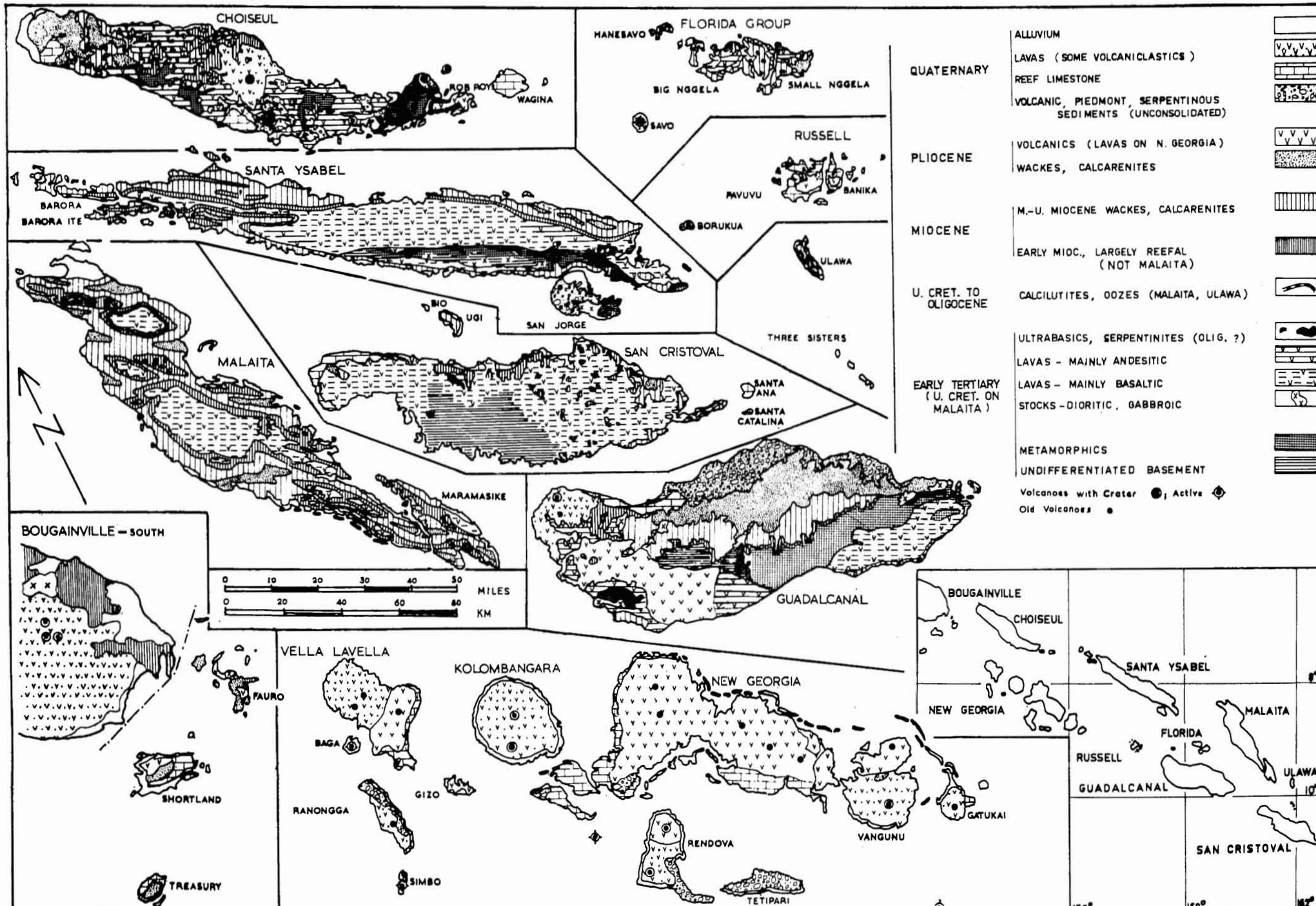

FIG. 6. Geological sketch map of the Solomon Islands.

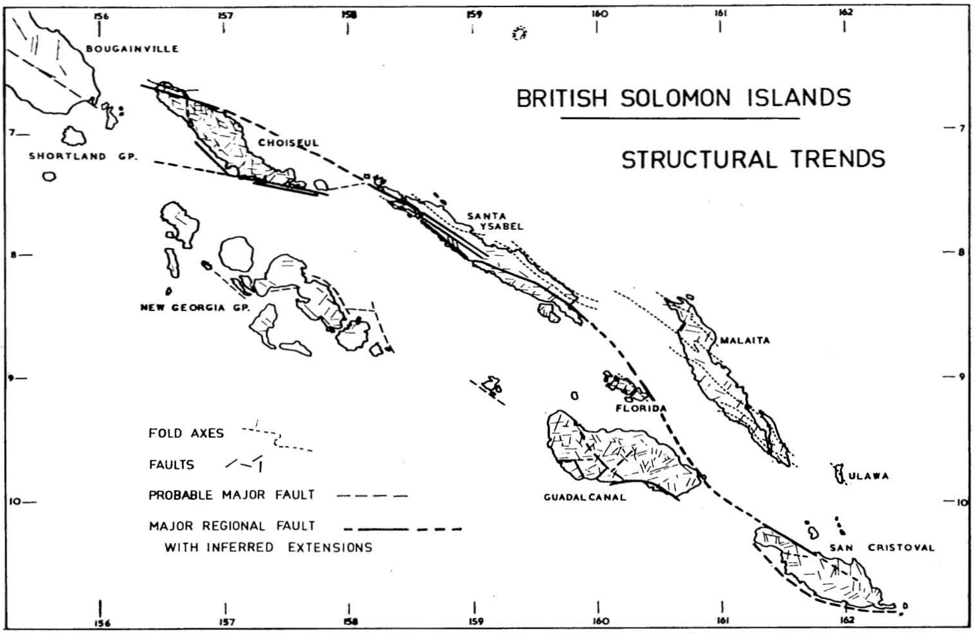

FIG. 7. Structural trends in the Solomon Islands.

may be up to 1,000 meters thick. They are overlain by a pile of reefal sediments, pyroclastics, rare lavas, and sediments derived from all of these and also the rocks of the basal complex. The quartz content is extremely low, so there are no quartzose sediments. The sediments range in age from early Miocene through Recent. They were deposited in subsiding fault-bounded troughs, one such trough in eastern Guadalcanal accumulating over 5,000 meters of sediment.

The structure of the Central Province is of horst and graben type, the blocks and troughs shaped mainly by the interaction between two major sets of faults, one set trending NW (310 to 330 degrees), the other W (260 to 280 degrees). A third, tensional set of fractures is also important and trends approximately NE (40 to 60 degrees).

Most faults appear to be normal, with northerly dips and with strong strike-slip components (Hackman, 1969). Some of these are antithetic to larger faults which are possibly the fundamental shaping fractures, but no simple basic pattern as yet emerges. The intensity and complexity of the fracturing is further complicated by the likely fact that at different times during the Cainozoic one or other of the fault sets has played the dominant role. On Guadalcanal, the suggestion is that during the lower Tertiary the NE and W sets were dominant, the former having the greatest strike-slip, dextral, movement. In the middle Tertiary the latter took over, the movement now being sinistral. More recently, the set trending NW has had a major shaping influence, with dextral strike-slip movement. The north coast of western Choiseul with its off-setting of fault blocks shows this particularly well.

This intense fracturing has produced a systematic result only on Guadalcanal which has a spine of block-faulted ridges up to 2,600 meters high, asymmetric in cross section with a steep fall-away to the southern coast. Much of this coast, as also the coasts of Choiseul and San Cristobal, appears to border complementary, foundered off-shore blocks.

Although it is probably true that the Central Province has been more or less continuously mobile since the late Cretaceous, nevertheless there were times of accentuated uplift activity and deformation by faulting. These were, approximately: late Paleocene, Oligocene, Upper Miocene, and Quaternary. Recent work, indeed, suggests that much of the uplift which has produced

Guadalcanal's block-mountain spine (highest point nearly 2,600 meters) took place in the Quaternary (B. D. Hackman, personal communication).

The boundary between the Central and Pacific provinces is marked by a fracture system which appears sigmoidal but is actually made up of straight faults, alternating in trend; the two trends are again the common ones, that is, roughly 310 to 330 degrees and 260 to 280 degrees, respectively. These faults are especially well developed on Santa Isabel (the Korigole Thrust: Stanton, 1961) and on Choiseul (Coleman, 1962) (again, Fig. 7).

This fracture system is the locus of a serpentine belt (there are other serpentine bodies on Guadalcanal which are related to major fractures, especially the NE-trending set). The serpentinous ultrabasics on Choiseul are flat-lying, in places almost horizontal. This relatively unusual attitude is explained as the result of the foundering of a thrust sheet. The erosion products of the serpentinites first appear in Lower Miocene sediments, so that an initial emplacement in the Oligocene is probable. On Santa Isabel they were remobilized in the late Tertiary and Quaternary and were easily weathered to yield serpentinous sediment which flows and blankets large areas.

The Pacific Province contrasts markedly with the rest of the Solomon Block. It shows best on Malaita. Here there are highly basic basal lavas (postulated as original seafloor) which are overlain concordantly, but irregularly, by deep-water foraminiferal oozes of Upper Cretaceous (Senonian) age (Coleman, 1966*b*). These, in turn, are overlain by about 1,300 meters of foraminiferal organogenic calcilutites of Cainozoic age, without apparent break. Some of the Eocene sediments were intruded by contemporaneous submarine lavas. They include highly mafic types akin to alnöite and ankaratrite; similar exotic lavas have been reported from the Lihir group at the western end of the group (Allen and Deans, 1965).

The older sediments consist of calcareous clay (up to 80 percent), acid-insoluble clay (up to 20 percent), and planktonic foraminifera (up to 20 percent) with occasional arenaceous benthonic foraminifera, radiolaria, and shards of volcanic glass. In some layers, usually associated with radiolarian chert bands, there may be up to 5 percent of a complex marine manganese mineral.

There is at least one relatively shallow-water benthonic fauna, of Upper Eocene age. The Upper Miocene and younger sediments show an increasing amount of terrigenous (volcanic) material. There are no reefal sediments or lithic terrigenous arenites. Malaita did not experience subaerial erosion before the Pliocene.

The whole sequence is faulted and (unusual for the Solomons) folded with moderate intensity into a series of rather irregular folds trending NW (310 to 330 degrees) and disposed en echelon to the run of the island. There is some cross-folding, usually at about 40 to 60 degrees. The folds show cascading and other evidence of deformation before consolidation so that, in general, the folding is considered to be of *Bruchfalten* type, brought about by movement of blocks in the faulted basement, during and following sedimentation. The faults trend mainly WNW (roughly 300 degrees) and NE, parallel to the cross-folding. The general structure and history is portrayed, as it were in model form, by the magnificent series of marine seismic profiles obtained east of Malaita by Woollard and his colleagues (1967).

Deformation on Malaita has probably been intermittently continuous from early Tertiary time to the present (topographic and structural highs coincide), but there were at least two major phases, one in the Eocene, another in the Upper Miocene.

The marginal areas of Santa Isabel, and, possibly, northeastern San Cristobal and the northwestern tip of Choiseul, have thinner sequences which are generally more contaminated by terrigenous erosional detritus.

The present-day proximity of Malaita to Guadalcanal, with their severely contrasting stratigraphies and structures, poses a problem. In particular, it is surprising that effluent from the great sediment-filled trough in eastern Guadalcanal (the Aola Trough: Coleman and Day, 1965; and Fig. 6) has not registered more strongly in the Malaitan succession. In general, the contrast between the Pacific and Central provinces at least suggests that the two may once have occupied different relative positions. The postulate is that Malaita, at least, began a westward movement relative to the Central Province, probably in the Upper Miocene.

Taking the Block as a whole, a few other points are worth emphasis. The Pacific Province has the oldest rocks, the Volcanic Province the youngest. There is a gradation in age of lavas from the Pacific flank to the Australian one, each Province having distinctive lava suites. The oldest (early Miocene) terrigenous sediments are found widespread in the Central Province. The problem of source areas for these great volumes of sediment, filling deep troughs in the Guadalcanal area, is a difficult one. The present mountain axis to the south of the island is too young to have served as source. San Cristobal, essentially a planed-off lava block, has been suggested as providing the great volume of volcaniclastics required (Coleman, *in* Rose et al., 1968). There is no real evidence for this nor for the earlier suggestion that the source area is now foundered in deep water off southern Guadalcanal (Coleman, 1965). Despite its connotation of "yo-yo" tectonics, the earlier idea is again favored: there is increasing evidence that the Solomons–New Hebrides region is one in which there have been extremely rapid vertical movements, exceeding 3,000 meters, of large crustal blocks. This idea, incidentally, highlights the importance of future detailed bathymetric studies around and about the islands, for this movement is probably still going on.

The correspondence between the geology and the pattern of gravity values is generally close. On a regional scale, the Solomon Block is a gravity high with superimposed positive anomalies of up to 250 milligals on land. These suggest that the Block is in a state of isostatic imbalance with great vertical displacement of crustal and subcrustal blocks. New Georgia Sound is marked by a comparative low, suggesting, as might be expected, a considerable thickness of sediment (2 km: Kroenke, *in* Rose et al., 1968). The largest land values are found along the trench or the Australian margins of the southern islands. These values increase still further to the south, and their distribution is reflected by the bathymetry and its suggestion of a SW-trending connection, between the middle part of the Solomon Block and the Louisiade-Pocklington-Rennell Ridge, by a set of submarine horsts and graben (Figs. 1 and 4).

Within the Solomons the highest gravity values are found along the southern edges of individual islands (Malaita is an exception: here, the gravity highs tend to coincide with lava cores of the larger anticlines).

The distribution of the more obvious ultrabasics is clearly indicated by high anomalies, as also of the associated major fractures—for example, the Korigole Thrust on Santa Isabel and the great fracture zone which defines southeastern Choiseul and continues east to Santa Isabel (defining, incidentally, the northwest edge of the New Georgia Sound rhombochasm).

In a general way, the oldest rocks on the various islands are marked by high gravity values (exceeding 200 mgals on Guadalcanal), despite the usual high topographic position of these rocks. This may result in extremely high gradients. For example, in eastern Guadalcanal the difference in levels between the base of the sedimentary section in the Aola Trough (with perhaps 6,000 meters of sediment) and the top of the adjacent ridges of basement rocks (onto much of which the sediments lap) is more than 8,000 meters. This difference is expressed over a horizontal distance of about 25 km. The gravity gradient here is one of the highest ever recorded.

The composite-block character of the islands is well reflected, especially by the gravimetric pattern on Choiseul. The collapsed volcano complex of which the Russell Islands are now the remaining northern part is also indicated clearly. Other correlations between geology and gravity are well illustrated in Grover (1968) and in Laudon (1968).

GEOLOGY OF THE NEW HEBRIDES

The regional geology of the New Hebrides Archipelago is described in a paper by Mitchell and Warden (1970), to which the reader is referred for particular detail.

The New Hebrides Block, as with the Solomons, is an autochthonous geological entity—although there is some slight evidence suggesting a closer association with the Fiji group, in the early Tertiary, than would appear from their present geographic separation. It also is intensely fractured, the islands having been shaped by faults. Folding is minor and incidental. The elongated shapes of the islands reflect the dominance of a fault set with strong meridional trends, acting along with a W–E set. The disposition of some of the minor volcanic cones and the trends of magnetic anomalies suggest that the latter is a tensional set and of special interest because it so clearly cuts across the "grain" of the Block. This, in turn, may reflect a subcrustal arching of the Block.

Although lacking the clear-cut character of the Solomons subdivision, the New Hebrides Block is made up of three areas of distinctive geological style: the Western Belt, the central volcanic chain, and the Eastern Ridge.

The Western Belt and Eastern Ridge are the oldest. Their history began probably in the early Tertiary but most of the rock successions are younger than Oligocene and, in the Western Belt, have close similarities with those of the Central Province in the Solomons. The central volcanic chain is the equivalent of the Solomon Volcanic Province and also had its beginning in the Pliocene. There is no equivalent to the Pacific Province.

The central volcanic chain is made up of the Santa Cruz (in part only) and Banks groups in the north; Aoba, Ambrym, and the Shepherd group in the center; and Efate, Erromango, Tanna, and Aneityum in the southern "tail." These are volcanic islands and island clusters disposed along a line parallel to, but a little east of, the axis of the New Hebrides Block.

As in the Solomon Volcanic Province, the larger islands are made up of coalesced accumulations of volcanic effusives and detritus and reefal sediments emergent from sea depths as great as 2,000 meters. The older of these have been block-faulted and partly uplifted, resulting in horst and graben structures. The smaller islands are usually single volcanoes and consist entirely of subaerial extrusives.

In the northern part of the chain the volcanics are dominantly basaltic, those of Utupua and Vanikoro (southern Santa Cruz group) including ankaramites and olivine-labradorite-basalts. In the central portion and south they are more variable and include, as the main representatives, feldsparphyric olivine basalts and basaltic and hypersthene andesites. Some eruptions have included both basaltic and andesitic rocks at the same time. In describing the central part of the chain, Warden (1967) stressed this variability in composition both in space and time. In general, he concluded that the basal parts of the volcanic sequences are essentially basaltic, passing up into mainly andesitic pyroclastics and flows. Recent eruptions at several vents included dacitic pumice and clasts of rhyolitic composition. Although not all volcanic piles show it, there is thus a tendency for the volcanics to become less basic with time.

There are at least eight active centers: Tinakula (Santa Cruz group) in the north; Vanua Lava and Gaua (Banks group); Ambrym (a splendid caldera) and Lopevi; two submarine volcanoes—one off eastern Epi, the other off northeastern Erromango; and Tanna in the south. Tinakula, Vanua Lava, Gaua, and Ambrym have passed through a caldera-forming stage; Ambrym is a fine example (Stephenson et al., 1968). Yasour, on Tanna, is a very young cone, but it represents the recrudescence of an older extremely large volcano which exploded paroxysmally. Lopevi and the submarine vents are young and at the cone-building stage. Some of the associated inactive volcanoes of the central portion of the chain have dissected cones but most are well preserved: Aoba is an essay in vulcanological features (Warden, 1968), and has a marked E–W elongation as well (Fig. 8).

The central chain is intensely fractured. The major fractures are aligned roughly NNW–SSE and E–W, the volcanic vents being disposed along one or the other of these, with a concentration of activity where they intersect. Malahoff's aeromagnetic data[4] show this relationship clearly, the influence of the E–W trending fractures standing out particularly well. The principal volcanoes in the central chain are associated with bipole magnetic anomalies of up to 1,000 gammas and suggest the presence of magma chambers relatively near the surface and having a tendency to E–W elongation.

Unlike the Solomons, the volcanic central chain is not marginal but is placed between two areas of differing and older geology. It can, nevertheless, be considered a version of the Western Belt as the latter was in the early Miocene: just as the Solomon Volcanic Province is a youthful extension of its Central Province.

---

[4] Malahoff, in preparation.

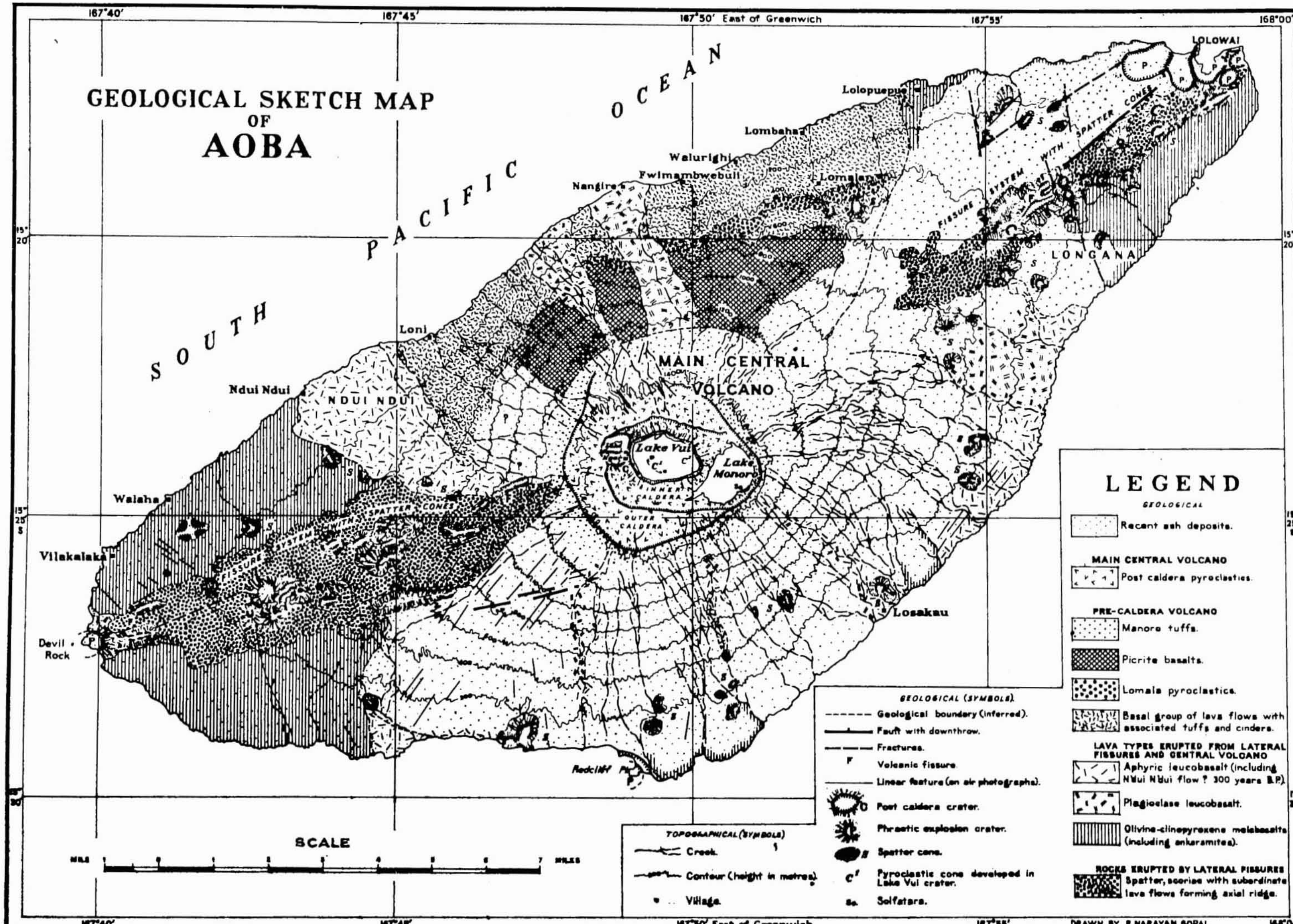

FIG. 8. Vulcanological features of Aoba, central New Hebrides (from Warden, 1967).

Santa Cruz Island, the Torres group, Espiritu Santo, and Malekula are the islands of the Western Belt. Santo is the largest island in the Archipelago and may serve as a model for the geology of the Belt (Robinson, 1968; 1969). It is divided neatly into two tectonic elements, the western mobile element and the eastern shelf (Fig. 9).

In western Santo, the oldest rocks are pre-Miocene andesitic and basaltic lavas (often autobrecciated), flow breccias, pillow lavas, and occasional pyroclastics. An older limit to these volcanics has not been set, nor whether they are truly basal. If they are, the older age limit is probably Eocene. Associated with the volcanics are stock-like intrusions of dioritic and gabbroic rocks which may be marginally younger.

The basal volcanics are overlain disconformably and unconformably by a sedimentary pile, perhaps over 3,000 meters thick and varying in age from early Miocene through Quaternary (as with the Central Province of the Solomons). There are no quartzose sediments. The older sediments are calcareous, dominantly algal/foraminiferal reefal limestones (not coralline), which are overlain by, and in the younger parts pass laterally into, wacke-type sediments and volcanics. The wackes, in volume and area, are the dominant sediments on Santo and in places occupy most of the column. They span the Miocene and were clearly derived from rapid erosion of a mountainous source area similar in composition to the basal volcanics.

The Miocene sedimentary sequence is charac-

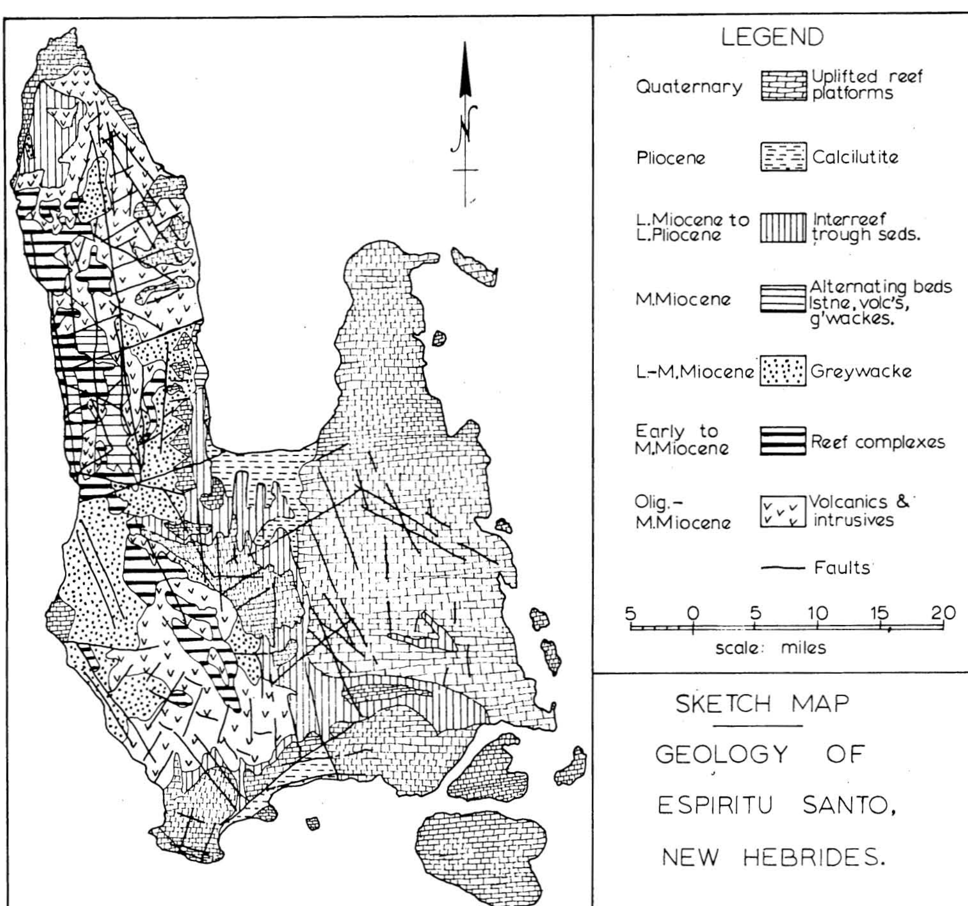

FIG. 9. Geological sketch map of Espiritu Santo, Western Belt, New Hebrides (after Robinson, 1968).

terized by complex facies changes. Particularly in the central part of the Cumberland Peninsula, the dominant wackes repeatedly pass laterally into andesitic volcanics including interbedded flows. Elsewhere, especially on both sides of the Peninsula and in southwest Santo, the wackes become more calcareous and organogenic, with occasional irregular reef bodies (probably marginal to the old volcanic highs). Between these marginal reefs, the sequence is one in which beds of calcarenite alternate with calcilutite beds rich in planktonic foraminifera, indicating free access to open ocean. These off-shore, inter-reef beds range through the Pliocene but then give way, probably unconformably, to a Plio-Quaternary coralgal reef limestone which covers part of western and all of eastern Santo.

The volcanics mentioned, associated both with the oldest, early Miocene reef limestones, and the Miocene greywackes, represent vulcanism and intrusion intermittent through the Miocene. They probably represent the sporadic continuation, in time and space, of the pre-Miocene vulcanism.

The dominant lava types are feldsparphyric basalts and andesites, the basalts tending to bulk larger in the pre-Miocene and early Miocene parts of the sequence. Massive flows and intrusions are not volumetrically dominant. The most common are autobrecciated lavas, which often pass laterally into volcanic rudites, then into peperites, and so into volcanic lithic calcarenites. Fringing-reef bodies may also be a part of this gradation from volcanic to shallow marine shelf environments. The coral content of the reef masses does not become prominent until well into the Pliocene.

As Robinson emphasizes, there is great variation in the chemical and mineralogical content of the lavas and associated volcanics, so that only in a general way can they be described as calc-alkaline. The hornblende diorites of southwestern Santo are more definitely calc-alkaline. There are several large, stock-like bodies of these rocks. They range in probable age from late Oligocene through Miocene. Mitchell and Warden (1970) relate them genetically to the andesitic volcanics.

The gabbros occur in small, isolated, usually fault-bounded bodies which have not been successfully related to the associated volcanics. They may represent a distinct set of intrusions (one such body is reported to be serpentinized).

The Western Belt is intensely fractured by systems of faults. Folding is incidental and minor. The faults are in three main sets, trending roughly N, NW, and W, respectively. Those with N and W trends seem to have been the dominant shaping sets.

Interaction between the faults resulted in differentially uplifted blocks, tending to be elongated meridionally, and the formation of horst and graben. At least until the Middle Miocene some of the highs were centers of vulcanism. Movement of the blocks was continuous throughout the Tertiary, so that the sites accumulating sediment were not constant but shifting. In a general way, the Western Belt was built up from west to east.

This picture of sedimentation from local sources into transient fault troughs explains the complicated facies changes, lateral and vertical, and rapid thickening and thinning of individual formations, so characteristic of the Santo column (see also the Malekula section, Fig. 10).

The eastern shelf of Santo is covered by Pliocene (? Upper) and Pleistocene reefal, flat-lying sediments which have lapped onto marginal areas of the western mobile element. What underlies these sediments is not known, but Robinson (1968) suggests a basement of volcanics of late Oligocene or early Miocene age, that is, an extension of the basal rocks of the western element. Most of the uplift proceeded during the Pleistocene and continues, as evidenced by the high incidence of shallow-focus earthquakes today. The uplift has been in stages, the periods between being represented now by exceptionally well developed reef terraces.

The fracture pattern over the eastern shelf is essentially the same as in the west, but N and NW trends are dominant.

The geology of Malekula, the second largest island in the Archipelago, is essentially similar to that of western Santo (Mitchell, 1966; 1968). In the basal (early Miocene) part of the sequence, flows and pillow lavas are rarer than they are in Santo, but thick, turbiditic, coarse volcanic arenites and rudites are more common, as also are intrusive dikes and sills. Massive reef bodies are not as well developed (Figs. 10 and 11).

The turbiditic greywacke sediments are especially prominent in the Middle Miocene, but they are not as regularly interspersed with planktonic foraminiferal silts. Mitchell (1966) places a major unconformity, not apparent in Santo, between Middle Miocene and Pliocene sediments. The latter consist of conglomerates, sandstones, and minor limestones deposited in a fault-trough and inter-reef environment. Although heavily eroded, a flat-lying Quaternary plateau limestone, similar to the Santo occurrence and with equally fine terraces (Mitchell, 1969), completes the Malekula succession. There is no equivalent to the eastern Santo shelf.

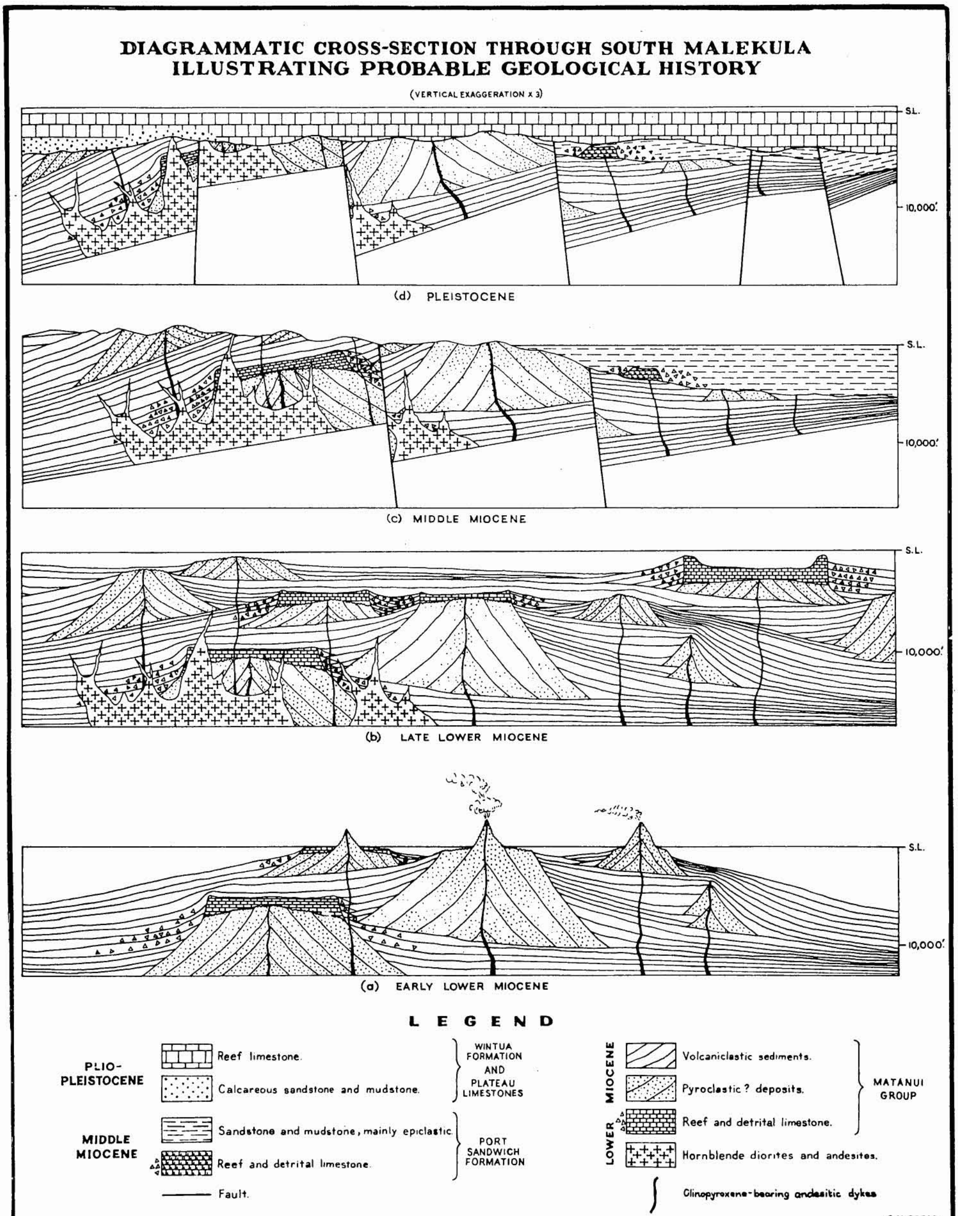

FIG. 10. A scheme of development for South Malekula, Western Belt, New Hebrides (from Mitchell, 1967).

Mitchell and Warden (1970) quote thicknesses of 6,000 meters for the Lower Miocene, 2,300 meters for the Middle Miocene, and over 500 meters for the Plio-Quaternary sequences. The first two values are remarkable. In Santo, similar values result if the maximum thicknesses of all units are added, but after allowing for likely repetition by faulting and rapid lateral thickening and thinning of each formation, a total of 3,000 meters seems more likely.

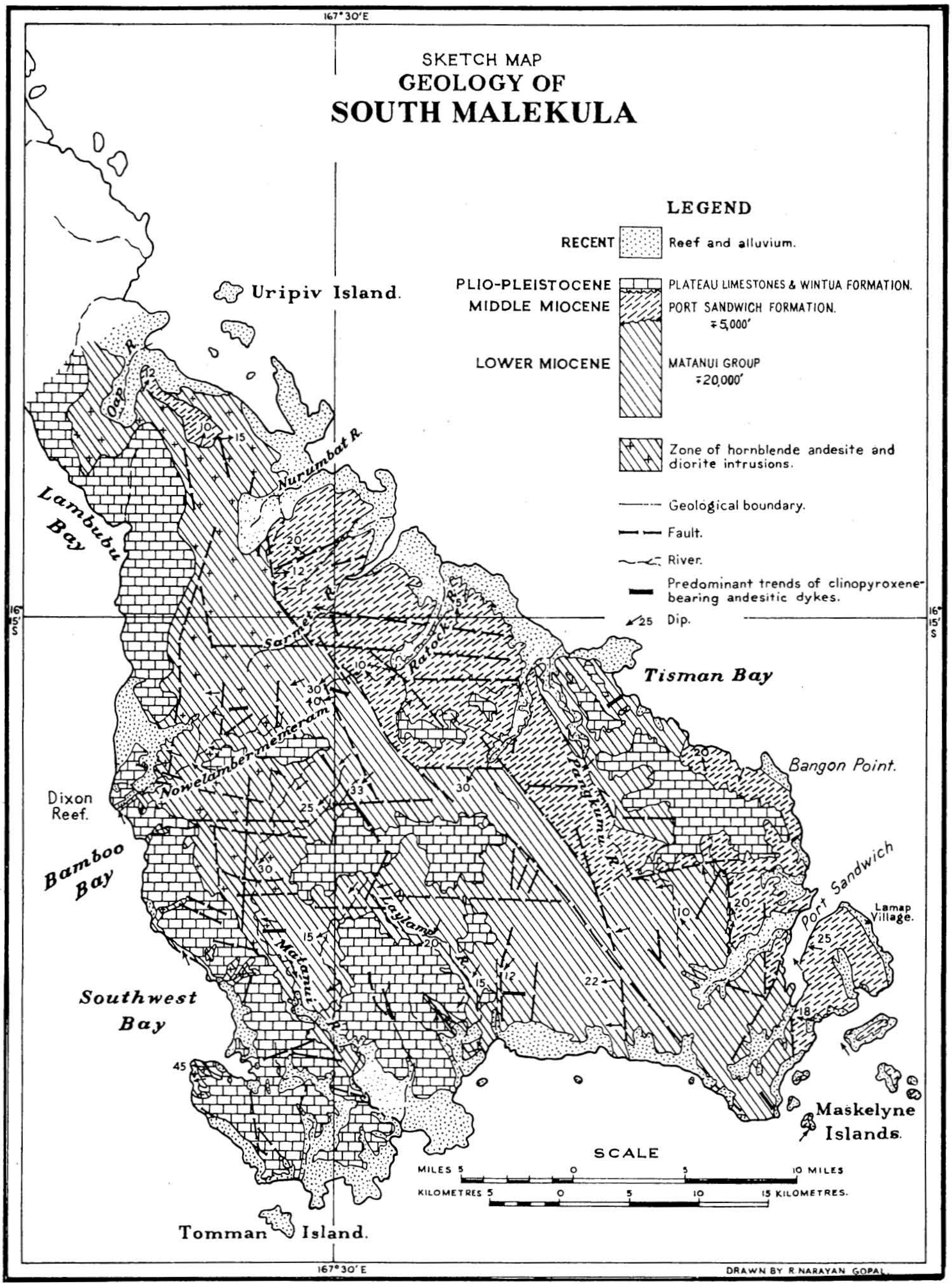

FIG. 11. Geological sketch map of South Malekula, Western Belt, New Hebrides (from Mitchell, 1967).

The Torres group, to the north of Santo, has not yet been surveyed. Preliminary work suggests that the islands consist of andesitic lavas (one of which gave a radiometric age of 39 ± 5 m.y.) and pyroclastics and some marine volcanic arenites, possibly of Lower Miocene age.

Santa Cruz Island deserves special mention for, until very recently, it, along with the other islands of the Santa Cruz group, was considered to be a Quaternary volcanic center. It has now been surveyed by the Solomon Islands Geological Survey, and a large area and volume of marine volcanic and calcareous sediments have been discovered. Samples of these sediments have been examined by the writer and found to range back in age to the early Miocene. With the Director's permission, P. M. Craig, Solomons Survey geologist, has generously provided the following preliminary summary of the geology:

> The exposed volcanic basement of Santa Cruz Island consists of two adjacent piles. In both, reworked pyroclastics which contain an early Miocene microfauna are predominant with basaltic lava flows becoming less common upwards. The flows of the eastern pile tend to be more numerous, thinner, and more porphyritic. Overlying both piles are calcareous sediments. The western pile passes rapidly up into a uniform succession of limestones and mudstones. The eastern pile, however, passes gradually upwards into calcareous grits which, in turn, pass upwards into finer grained, more calcareous horizons. An unconformable mantle of reef limestone obscures much of the eastern pile, the coastal margins of the western pile, and forms a large uplifted plateau still further west.
>
> Vertical faulting appears to be the main structural control, there being little evidence for lateral fault movements or of folding. Directions of major faults tend to parallel the long and short axes of the island.

The early Miocene (Tertiary upper 'e') fauna referred to is the "*Spiroclypeus-Eulepidina*" or "San Jorge" fauna (Coleman, 1963), wide ranging from northern coastal New Guinea through the Solomons, New Hebrides to Fiji. The eastern pile on Santa Cruz Island appears to have a more complete section than the western, including younger fauna. The dominance of faults trending N and W fits the general New Hebrides pattern.

The Eastern Ridge consists of Maewo and Pentecost islands. Both are narrow, elongate, steep-sided slabs shaped by faulting, and have much of their central and northern areas obscured by a probable Quaternary, reefal limestone cover, uplifted over 800 meters in places. Detailed work is still going on (Liggett, 1967; Mallick, 1969) (Figs. 12 and 13).

Maewo has the oldest sediments so far dated in the eastern belt. These are early Miocene turbiditic wackes and conglomerates, possibly overlying basalts, with clasts of varying lithologies, including volcanics and Upper Eocene limestones (remarkably similar in fauna and lithology to those found in the Wainimala Group of Viti Levu, Fiji), neither of which has been found *in situ* anywhere in the New Hebrides. These old sediments crop out along the eastern coast. In the center and north of Maewo, the basal sediments, perhaps 800 meters thick, give way to finer grained wackes and calcilutites of about the same total thickness and of Miocene age.

The volcanic content increases, in a general way, to the south, for over the southern half of the island there are large areas of basaltic lavas, breccias and associated pyroclastics, and interbeds of calcilutites. Both massive flows and pillow lavas occur; dikes and other intrusions are fairly rare. These volcanics are at best several thousand feet thick and, while the bulk of them is probably Miocene, the oldest may pre-date the Miocene and thus form the basement rocks of the island.

The Pliocene (about 300 meters) is represented by calcilutites rich in planktonic foraminifera, and calcarenites which appear to be conformable on the Miocene. Intrusions of basalt have been recorded. To the north, these pass into banded beds with an increased terrigenous content.

The Quaternary limestone cover (up to 330 meters thick) has an irregular base, probably of varying age, but over large areas it takes on the form of a single sheet. It is coralgal, but the coral is scattered and there do not seem to be any reef frameworks structured in coral. Apart from its obscuring physical presence, it is responsible for much mantling of the older rocks with travertine. It is obviously but a part of a much larger original area of reefal carbonate sedimentation.

The sedimentary succession has a regional westerly dip of 20 to 30 degrees, remarkably consistent in view of the fracturing and uplift which have taken place. The fracture pattern is made up of two sets of near-vertical normal faults, one with a northerly trend, 350 to 020 degrees approximately, the other westerly, 265 to 290 degrees. Great scarps with these orientations are spectacular features of the present topography.

The geology of Maewo suggests that it was

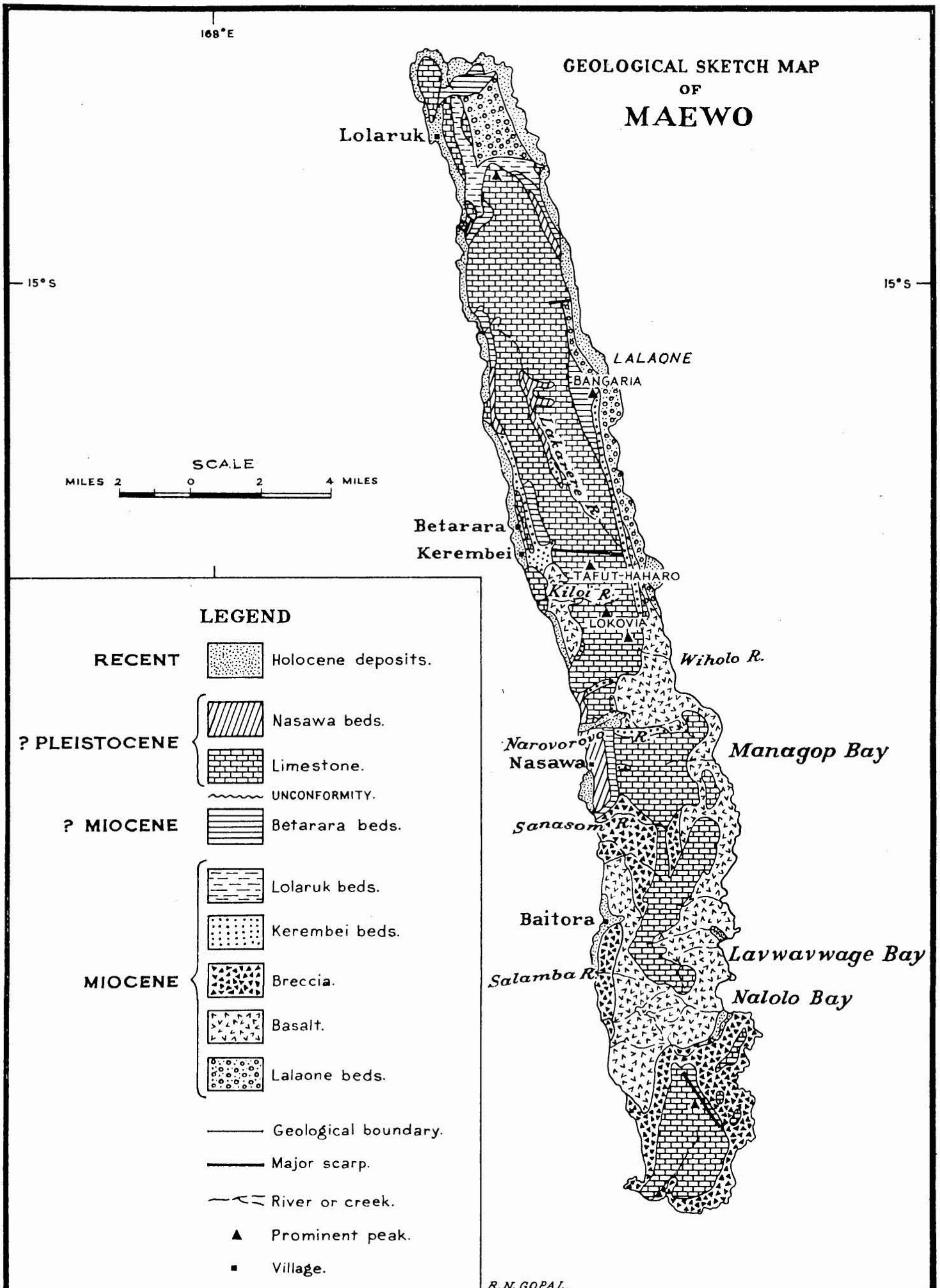

FIG. 12. Geological sketch map of Maewo, Eastern Ridge, New Hebrides (from Liggett, 1967).

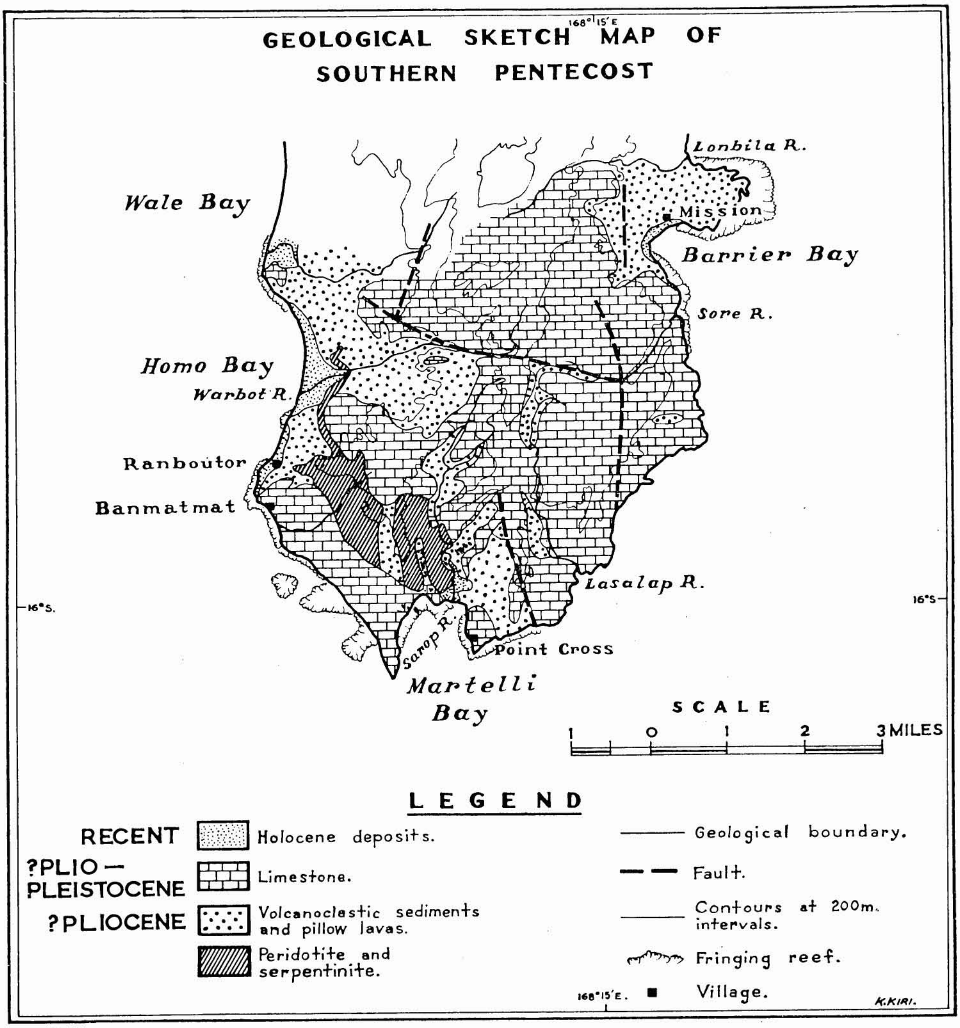

FIG. 13. Preliminary geological sketch map of southern Pentecost, Eastern Ridge, New Hebrides (from Mallick, 1969).

once a part of a larger entity. The eastern part has foundered; the western edge has been uplifted, not as a single slab or sliver but as a set of blocks at different rates, as reflected in the irregular base of the Quaternary limestone and the larger exposures of lavas in the south. The uplift probably began in the Pliocene but most of it took place in the late Quaternary and may still be proceeding.

Pentecost (or Raga, the indigenous name) is something of an anomaly. The oldest rocks are exposed in southern Pentecost. A provisional statement on the geology is given by Mallick (1969). Southern Pentecost is especially noteworthy because it alone of the New Hebrides Islands has large areas of ultrabasics. These rocks are largely enstatite olivinites and are extensively serpentinized (there is a record of a small serpentinite body in central west Santo). They are similar to the Solomon Islands serpentinites, especially those of Santa Isabel and Choiseul, and like them, they weather rapidly to a clayey serpentinous sediment which drifts readily and obscures the relationships of the ultrabasics to the associated rocks. The latter consist of submarine volcanics (apparently intruded in part by the ultrabasics) which include submarine basaltic lavas, breccias and lithic volcanic rudites, and arenites. The finer grained of these sediments may range into calcarenites and, especially, calcilutites. There are interspersed beds of calcilutites which are extremely rich in planktonic foraminifera (amounting to pelagic oozes) but have little volcanic material. There are lavas as well, particularly pillow lavas, which occur at various levels within the sediments. The oldest sediments so far dated are Upper Miocene in age. Some of them include serpentinite detritus which puts the age of emplacement of the serpentinites before this time. No Lower Miocene terrigenous sediments of the Maewo or Santo kind have been found up to the time of writing, although the field work (by Mallick, on a 1:50,000 scale) is now nearly complete.[5]

Northern Pentecost is only now being systematically surveyed. It includes a similar basal mixture of basaltic volcanics and calcilutites rich in planktonic foraminifera, indicating an Upper Miocene or younger age.

The fracture pattern on Pentecost is similar to that of Maewo, and is shown best over the southern half where large near-vertical fractures, trending 0 to 20 degrees, are especially conspicuous.

It would appear that Pentecost has experienced little subaerial erosion during its development and that it has had only one major episode of uplift, probably during the Quaternary.

For the New Hebrides, the gravity picture is much less detailed; shipboard studies have been confined to the northern end, and only over the central portion of the group may inter-island extrapolations be considered. Nevertheless, there are some interesting results (Malahoff and Woollard, 1969).

The Block is also a positive high with land values up to 200 mgals, the largest tending to be on the eastern, Pacific edge, the lowest, on the western, continental side, in direct contrast to the Solomons. In the Western Belt, Santo and Malekula show a N–S polarization of high positive anomalies, with a pole-in-common between the two islands. On Santo, the western part, in particular the Cumberland Peninsula, is shown separate from the eastern shelf. Robinson's postulate of a basement volcanic complex beneath the shelf is supported. The increasing thickness of sediment to the east of western Santo is well shown.

The intensity of the block faulting is not reflected, due probably to the wide spacing of the gravity measurements, but the fracture trends are suggested, especially the north and northwesterly ones. Some of the volcanic centers are clearly delineated by local anomalies, for example, Lopevi and Tongoa. The graben structure of Efate is indicated, as is also the remnant character of both Erromango and Tanna.

On the Eastern Ridge, the highest values are found along the eastern margins of Maewo and Pentecost. If the Solomons are a guide, still higher anomalies will be found further out to sea. The ultrabasics on Pentecost are only vaguely indicated, but areas of maximum Quaternary uplift on both Maewo and Pentecost relate well to the gravity pattern.

In the Solomons, the gravity values rise steeply as the southwestern trench areas are approached. The New Hebrides cover is sparse, but shows a parallel case in the Torres Trench area to the north. Perhaps significantly, the western central portion of the New Hebrides, occupied by Santo and Malekula, is a comparative gravity low: the offshore area here lacks a trench, separating as it does the Torres and New Hebrides deeps.

OUTSTANDING FEATURES, COMPARISONS, AND DEVELOPMENT

As composite fractured island chains, the Solomons and the New Hebrides are highly distinctive entities and as such are difficult to compare meaningfully with other island arcs, outside the Melanesian Re-entrant. The Caribbean complex may be an exception: Donnelly's description of the regional geology of the Virgin Islands hints at a parallel (Donnelly, 1964). Discussion of this and much closer parallels within the Melanesian Re-entrant is outside the purpose of this paper and is left to another time.

The Solomons and New Hebrides have the following noteworthy characteristics in common:

1. Both are crustal blocks, 20 to 30 km in

[5] April 1970: These sediments have now been found.

thickness, and isolated from neighboring blocks. Both are autochthonous geological systems which began their histories in the late Mesozoic or earliest Tertiary. Their generalized stratigraphic columns are remarkably similar and complete, without major break. These do not account for, nor suggest the nature of, the remaining major part of the estimated crustal thickness of each block. The transition from oceanic crust to that composing each block appears to be more abrupt on the trench side than it is on the northeast or Pacific side.

2. "Reverse" island arc features are shared in common: deep linear trenches on the continental side (not continuous but with a break in the middle); general absence of arcuate features; abnormally placed Holocene volcanic belts; submarine platforms on the Pacific side (Ontong Java Platform and Fiji Plateau); "planes of seismicity" which are either vertical or dip steeply away from the continental side.

3. They are areas of high gravity values, with large superimposed positive anomalies, on the flanks of an even greater regional high which is covered by the Coral and Solomon seas. They are highly seismic, the New Hebrides Block especially so. The distribution of hypocenters is irregular, more so in the Solomons, with a suggestion of a gap between about 200 and 400 km.

4. Deep fracturing is the dominant structural theme, and taphrogenesis, large and small scale, is its expression. Differential uplifts of up to 6,000 meters over short lateral distances are recorded. These are associated with extremely high gravity gradients. In general, surface tensional stress seems to have prevailed during the Tertiary and Quaternary. The geologically recent expression of this stress is a set of tensional faults which trends normal to the axis of each block.

5. Both blocks—at least over their central positions—are linked with the Louisiade-Pocklington-New Caledonia "high" by a complex of submarine features suggestive of horsts and graben.

6. The volcanic rocks include a great variety of basic and intermediate lavas, including highly mafic types such as picrite-basalt, ankaratite, alnöite, and ankaramite. Basalts and andesites are in about equal bulk, the oldest being the more basic. Petrogenetically, the lavas appear to have strongest affinities with the so-called circumocean suite.

7. Serpentinites, after eustatite olivinites and hartzburgites, occur in both blocks, the larger and better defined area, amounting to a serpentine belt, occurring in the Solomons.

8. Granitoid rocks of diorite type, ranging in age from Oligocene to Plio-Pleistocene, are comparatively rare. There are no granites nor quartzose sediments.

9. Terrigenous sedimentation, widespread in both areas, began in the early Miocene and was fairly continuous thereafter. Although algal/foraminiferal reefal sediments are a common element in their sedimentary columns, ranging back to the early Miocene, the coral content is surprisingly sparse; coral-structured reef masses do not become at all prominent until the Quaternary.

These similarities are important; but there are differences:

1. The Solomons have a folded terrain—the Pacific Province—with a highly individual stratigraphic succession, including at least 1,000 meters of late Cretaceous to Lower Miocene, deep-water organogenic oozes. There is no direct equivalent in the New Hebrides; Pentecost, with its comparative lack of terrigenous sediment and its essentially submarine history, comes nearest.

2. The distribution of hypocenters in the New Hebrides is more regular and, in a sense, more "normal," than it is in the Solomons.

3. The Solomons show a marked gradational development from the Pacific to the Australian margins. The New Hebrides lack this.

4. Strike-slip movement along faults is more evident in the Solomons. But the vertical differential movement between blocks, amounting to several thousand meters, within a time span of a few million years, is shown rather better by New Hebrides examples.

5. The Solomons experienced at least a mild form of regional, shearing, metamorphism in the early Tertiary. Regional metamorphics have not been found in the New Hebrides.

6. The New Hebrides stratigraphic column does not include pre-Tertiary sediments. The early Miocene sediments, however, include derived Upper Eocene shallow-water calcarenite clasts which could not have been transported

far. There is no shallow-water Upper Eocene sediment in the Solomons.

7. The highest positive gravity anomalies in the Solomon land areas are found on the trench or continental flank. In the New Hebrides they occur on the Pacific or Fiji Plateau side (further detailed gravity work in the New Hebrides may remove this contrast).

The similarities quite outweigh the differences, so that the same *generalized* scheme of development will serve for both areas (the New Hebrides lagging behind the Solomons in the beginnings of the earlier major events).

They began their history with the submarine extrusion or injection of basaltic lava piles beneath a cuirass of deep-water organogenic oozes during late Cretaceous (early Tertiary in the New Hebrides). The relationship of this emplacement to any underlying (? ocean floor) rocks is unknown. Build-up by way of deep tensional fractures continued, producing rhomboidal laval welts elongated more or less parallel to the axis of each block: in terms of their orientation *today,* this is NW–SE in the Solomons, N–S in the New Hebrides. By the Lower Eocene, some of the Solomon blocks were above sea level and receiving pyroclastics. A large part of the Solomons was then regionally metamorphosed (albite-epidote-amphibolite facies—but no evidence of this in the New Hebrides). Further vulcanism, upward movement of gabbro and peridotite, differential uplift of blocks and intrusion by stocklike masses of acid segregations from andesitic magma, all took place during approximately Oligocene time (peridotite emplacement in the New Hebrides was probably later). This was followed by a quiet stage with extensive build-up of reef and reefal sediments (*not* especially coralline) in the Lower Miocene (accompanied by vulcanism in the New Hebrides). Serpentinites were first exposed to erosion in the Solomons at this time. There was then renewed vulcanism and erosion of elevated blocks, with major uplift probably in the Middle/Upper Miocene, to produce great thicknesses of wacke-type sediments with occasional still-stages permitting the growth and accumulation of reefal sediments. The latter have increased coral content and a considerable admixture of warm-water planktonic foraminifera, suggesting free access of island waters to nearby ocean. Great uplift of sediment-filled troughs and foundering of eroded blocks, together with strike-slip movement (dextral) along NW–SE trending faults (most marked in the Solomons) has taken place in the Upper Pliocene/Quaternary. This was also the time of marginal accretion around most islands with uplift of reef slabs; in the Solomons there was a shift of intensified vulcanism to the southwest, and the intrusion of dioritic stocks; in the New Hebrides there was intensified vulcanism along the axis of the Block.

The Pacific Province has its own history. It began with crustal arching, block faulting, and intrusion/extrusion of basaltic lavas beneath deep-water, Upper Cretaceous (Senonian) pelagic oozes. This was followed by accumulation of the same sediments with faulting of the lava pile and initiation of folds of the *Bruchfalten* type. There was then minor intrusion of highly basic lavas and carbonate sedimentation (Eocene to Upper Miocene; up to 1,000 meters) most of it deep-water, but with at least one shallow-water intercalation in the Eocene. The Eocene was also a time of emphatic fault-block movement and widespread production of *Bruchfalten.* The terrigenous (volcanic) content of the sediments increased in late Miocene and Pliocene, and there was yet another major episode of uplift and folding in the late Tertiary. Mobility continued to the present, with some cross-folding and faulting, so that topographic and structural highs are coincident. The shift of this Province, probably from the east relative to the other parts of the Solomon Block, is thought to have begun in the late Miocene.

The possible shift of both the Solomon and New Hebrides blocks, from positions in an outer arc bordering continental Australia in the early Tertiary, is briefly suggested in an earlier paper (Coleman, 1967). It was proposed that this arc is now represented by the rim of the Melanesian Re-entrant.

LITERATURE CITED

ALLEN, J. B., and T. DEANS. 1965. Ultrabasic eruptives with alnöitic-kimberlitic affinities from Malaita, Solomon Islands. Mineralogical Magazine (London), vol. 34, pp. 16–34.

BLAKE, D. H., and Y. MIEZITIS. 1967. Geology of Bougainville and Buka islands, New

Guinea. Australia Bureau of Mineral Resources, Bulletin 93 (PNG 1), 56 pp.

CAREY, S. W. 1958. The tectonic approach to continental drift. In: Continental drift—A symposium, pp. 177–355. Geology Department, University of Tasmania, Hobart.

——— 1963. The asymmetry of the earth. Australian Journal of Science, vol. 25, pp. 369–383, 479–488.

COLEMAN, P. J. 1962. An outline of the geology of Choiseul, Solomon Islands. Journal of the Geological Society of Australia, vol. 8, pp. 135–158.

——— 1963. Tertiary larger foraminifera of the British Solomon Islands, southwest Pacific. Micropaleontology, vol. 9, pp. 1–38.

——— 1965. Stratigraphical and structural notes on the British Solomon Islands with reference to the First Geological Map, 1962. British Solomon Islands Geological Record, vol. 2 (1959–1962), pp. 17–31. Geological Survey, Honiara.

——— 1966*a*. The Solomon Islands as an island arc. Nature, vol. 211, no. 5055, pp. 1249–1251.

——— 1966*b*. Upper Cretaceous (Senonian) bathyal pelagic sediments with *Globotruncana* from the Solomon Islands. Journal of the Geological Society of Australia, vol. 13, pp. 439–447.

——— 1967. A possible resolution of the Melanesian Re-entrant. Upper Mantle Project, Second Australian Progress Report, 1965–1967, pp. 192–194. Australian Academy of Science, Canberra.

COLEMAN, P. J., and A. A. DAY. 1965. Petroleum possibilities and marked gravity anomalies in north-central Guadalcanal. British Solomon Islands Geological Record, vol. 2 (1959–1962), pp. 112–119.

COLEMAN, P. J., J. C. GROVER, R. L. STANTON, and R. B. THOMPSON. 1965. A first geological map of the British Solomon Islands. British Solomon Islands Geological Record, vol. 2 (1959–1962), pp. 16–17.

DONNELLY, T. W. 1964. Evolution of eastern Greater Antillean Island Arc. Bulletin of the American Association of Petroleum Geologists, vol. 48, pp. 680–696.

FAIRBRIDGE, R. W. 1961. The Melanesian Border Plateau, a zone of crustal shearing in the southwest Pacific. Publications du Bureau central sismologique international, 1960A, no. 22, pp. 137–149.

FURUMOTO, A. S., D. M. HUSSONG, J. F. CAMPBELL, G. H. SUTTON, A. MALAHOFF, J. C. ROSE, and G. P. WOOLLARD. 1970. Crustal and upper mantle structure of the Solomon Islands as revealed by seismic refraction survey of November–December 1966. Pacific Science, vol. 24, pp. 315–332. (In this issue.)

GROVER, J. C. 1968. The British Solomon Islands: Some geological implications of the gravity data, 1966. In: The crust and upper mantle of the Pacific area, pp. 296–306. Geophysical Monograph 12, American Geophysical Union, Washington, D.C.

——— 1969. Record of gravity, magnetic, bathymetric, aerial and crustal surveys in the British Solomon Islands, 1963–1966. British Solomon Islands Geological Record, vol. 3 (1963–1967). In press.

HACKMAN, B. D. 1969. The geology of east and central Guadalcanal: A preliminary statement. British Solomon Islands Geological Record, vol. 3 (1963–1967). In press.

KRAUSE, D. C. 1966. Bathymetry and submarine geology of the northern Tasman Sea–Coral Sea–Southern Solomon Sea region of the southwestern Pacific Ocean. New Zealand Oceanographic Institute, Memoir 41.

LAUDON, T. S. 1968. Land gravity survey of the Solomon and Bismarck islands. In: The crust and upper mantle of the Pacific area, pp. 279–295. Geophysical Monograph 12, American Geophysical Union, Washington.

LIGGETT, K. L. 1967. Preliminary report on Maewo. New Hebrides Condominium Geological Survey, Annual Report (1965), pp. 8–12.

MALAHOFF, A. In preparation. Gravity and magnetic studies of the New Hebrides island arc. New Hebrides Condominium Geological Survey Report.

MALAHOFF, A., and G. P. WOOLLARD. 1969. The New Hebrides Islands gravity network. Hawaii Institute of Geophysics Report 69–14, 26 pp.

MALLICK, D. I. J. 1969. Preliminary report on southern Pentecost. New Hebrides Condo-

minium Geological Survey, Annual Report (1967), pp. 20–25.
MAWSON, D. 1905. The geology of the New Hebrides. Proceedings of the Linnean Society of New South Wales, vol. 30, pp. 400–484.
MENARD, H. W. 1964. Marine geology of the Pacific. New York, McGraw-Hill. 271 pp.
MITCHELL, A. H. G. 1966. Geology of South Malekula. New Hebrides Condominium Geological Survey, Report 3, 40 pp.
——— 1967. Geological history of South Malekula. New Hebrides Condominium Geological Survey, Annual Report (1965), pp. 34–39.
——— 1968. North Malekula. New Hebrides Condominium Geological Survey, Annual Report (1966), pp. 28–34.
——— 1969. Raised reef-capped terraces and Plio-Pleistocene sea-level changes, North Malekula, New Hebrides. Journal of Geology, vol. 77, pp. 56–67.
MITCHELL, A. H. G., and A. J. WARDEN. 1970. Geology of the New Hebrides island arc. In press.
MIYAMURA, S. 1968. Seismicity of island arcs and other arc tectonic regions of the circum-Pacific zone. In: The crust and upper mantle of the Pacific area, pp. 60–69. Geophysical Monograph 12, American Geophysical Union, Washington, D.C.
OBELLIANE, J. M. 1958. Contribution à la connaissance géologique de l'Archipel des Nouvelles Hébrides (Iles Vate, Pentecôte, Maewo, Santo). Science de la Terre, vol. 6, pp. 139–368.
OFFICER, C. B. 1955. Southwest Pacific crustal structure. Transactions of the American Geophysical Union, vol. 36, pp. 449–459.
RICHARDS, J. R., J. A. COOPER, A. W. WEBB, and P. J. COLEMAN. 1966. Potassium-argon measurements of the age of basal schists in the British Solomon Islands. Nature, vol. 211, no. 5055, 1251–1252.
ROBINSON, G. P. 1968. Biostratigraphy and structure of Espiritu Santo, New Hebrides Archipelago, southwest Pacific. Unpublished doctoral dissertation, University of Western Australia.
——— 1969. Geology of north Santo. New Hebrides Condominium Geological Survey, Regional Report no. 1, 77 pp.
ROSE, J. C., G. P. WOOLLARD, and ALEXANDER MALAHOFF. 1968. Marine gravity and magnetic studies of the Solomon Islands. In: The crust and upper mantle of the Pacific area, pp. 379–410. Geophysical Monograph 12, American Geophysical Union, Washington, D.C.
RÜE, A. de la. 1937. Le Volcanisme des Nouvelles-Hébrides (Mélanésie). Bulletin volcanologique, ser. 2, vol. 2, pp. 79–142.
SAGATZKY, J. 1959. Contribution à l'étude géologique de l'île Espiritu Santo (Nouvelle Hébrides) 1. Roches sédimentaires. Bulletin de la Société géologique de France, ser. 6, vol. 8, pp. 501–509.
——— 1960. Contribution à l'étude géologique de l'île Espiritu Santo (Nouvelle Hébrides) 2. Roches volcaniques. Bulletin de la Société géologique de France, ser. 7, vol. 1, pp. 588–593.
STANTON, R. L. 1961. Explanatory notes to accompany a first geological map of Santa Isabel, British Solomon Islands Protectorate. Overseas Geology and Mineral Resources, vol. 8, pp. 127–149.
STANTON, R. L., and J. D. BELL. 1969. Volcanic and associated rocks of the New Georgia Group, British Solomon Islands. British Solomon Islands Geological Record, vol. 3 (1963–1967). In press.
STEPHENSON, P. J., G. J. H. MCCALL, R. W. LE MAITRE, and G. P. ROBINSON. 1968. The Ambrym Island Research Project. New Hebrides Condominium Geological Survey, Annual Report (1966), pp. 9–15.
WARDEN, A. J. 1967. The geology of the Central Islands. New Hebrides Condominium Geological Survey, Report 5, 106 pp.
——— 1968. Geology of Aoba volcano. New Hebrides Condominium Geological Survey, Annual Report (1966), pp. 15–27.
WOOLLARD, G. P., A. S. FURUMOTO, J. C. ROSE, G. H. SUTTON, A. MALAHOFF, and L. KROENKE. 1967. Cruise report on 1966 seismic refraction expedition to the Solomon Sea. Hawaii Institute of Geophysics Report 67-3, 31 pp.
WRIGHT, P. C. 1969. The pyroxene diorite intrusion of Mount Kanekolo, central-east New Georgia. British Solomon Islands Geological Record, vol. 3 (1963–1967). In press.